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(54) **SYSTEM AND METHOD FOR CELL BALANCING AND CHARGING USING A SERIALLY COUPLED INDUCTOR AND CAPACITOR**

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(Continued)

(51) **Int. Cl.**
H02J 7/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H02J 7/0019*** (2013.01); ***H02J 7/0014*** (2013.01); ***H02J 7/0016*** (2013.01); ***H02J 7/0018*** (2013.01); ***H02J 7/0052*** (2013.01); ***H02J 7/0081*** (2013.01)

(58) **Field of Classification Search**
CPC H02J 7/0016; H02J 7/0019; H02J 7/0014; H02J 7/0081; H02J 7/0018; H02J 7/0052

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Primary Examiner — Richard Isla
Assistant Examiner — Manuel Hernandez
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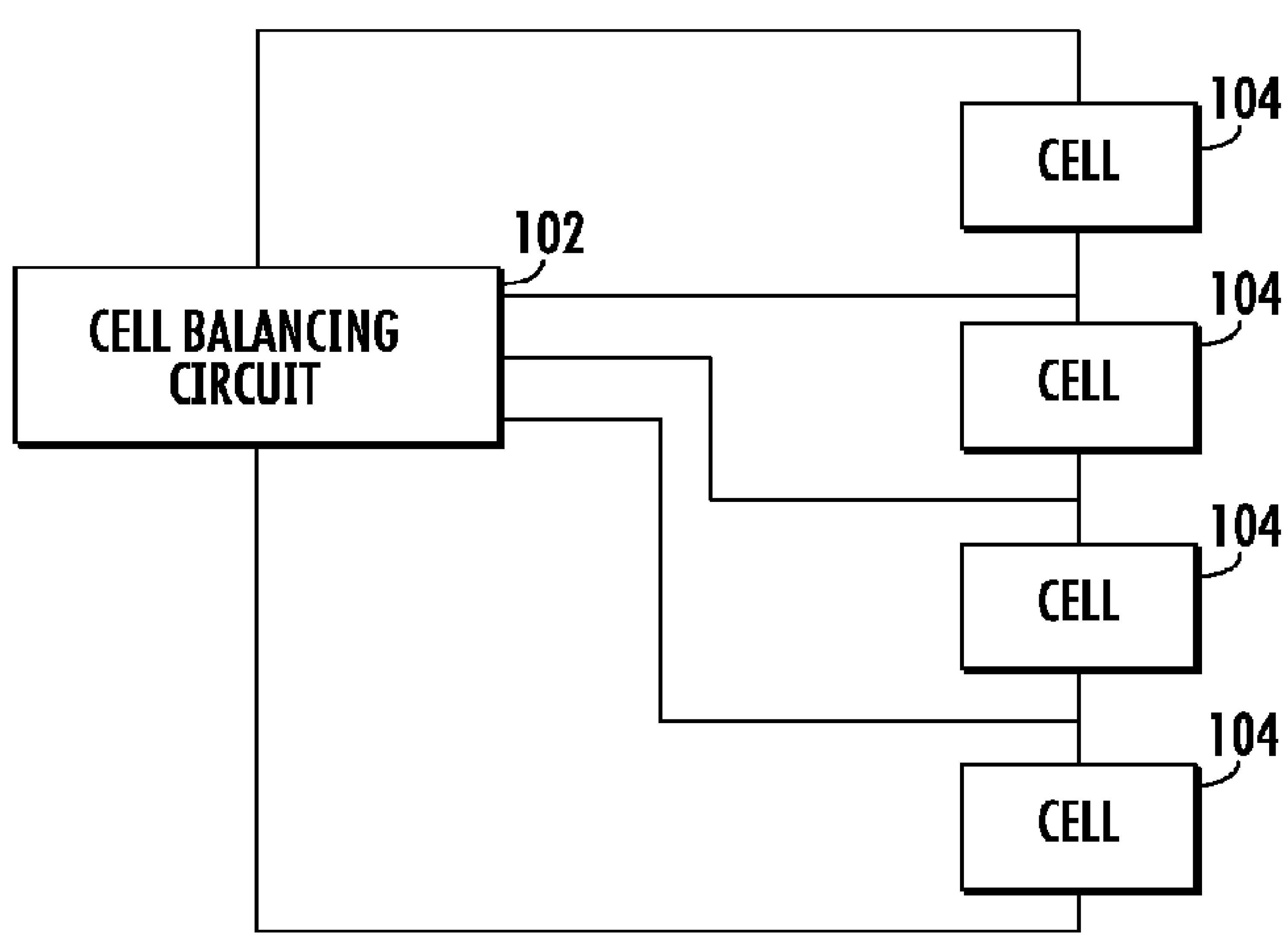
(57) **ABSTRACT**

An apparatus for charging a plurality of series connected battery cells, includes a first and second input terminals for providing a charging voltage to the plurality of series connected battery cell. A transformer includes a primary side associated with the charging voltage and a secondary side includes a plurality of portions. Each of the plurality of portions is connected across at least one of the plurality of series connected battery cell. A switch in series between each of the plurality of portions of the secondary side and the at least one of the plurality of series connected battery cells increases an impedance between the portion of the secondary side and the associated one of the plurality of series connected battery cells in a first state and decreases the impedance between the portion of the secondary side and the associated one of the plurality of series connected battery cells in a second state.

27 Claims, 11 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/180,618, filed on May 22, 2009, provisional application No. 61/244,643, filed on Sep. 22, 2009.

(58) **Field of Classification Search**
USPC 320/116
See application file for complete search history.

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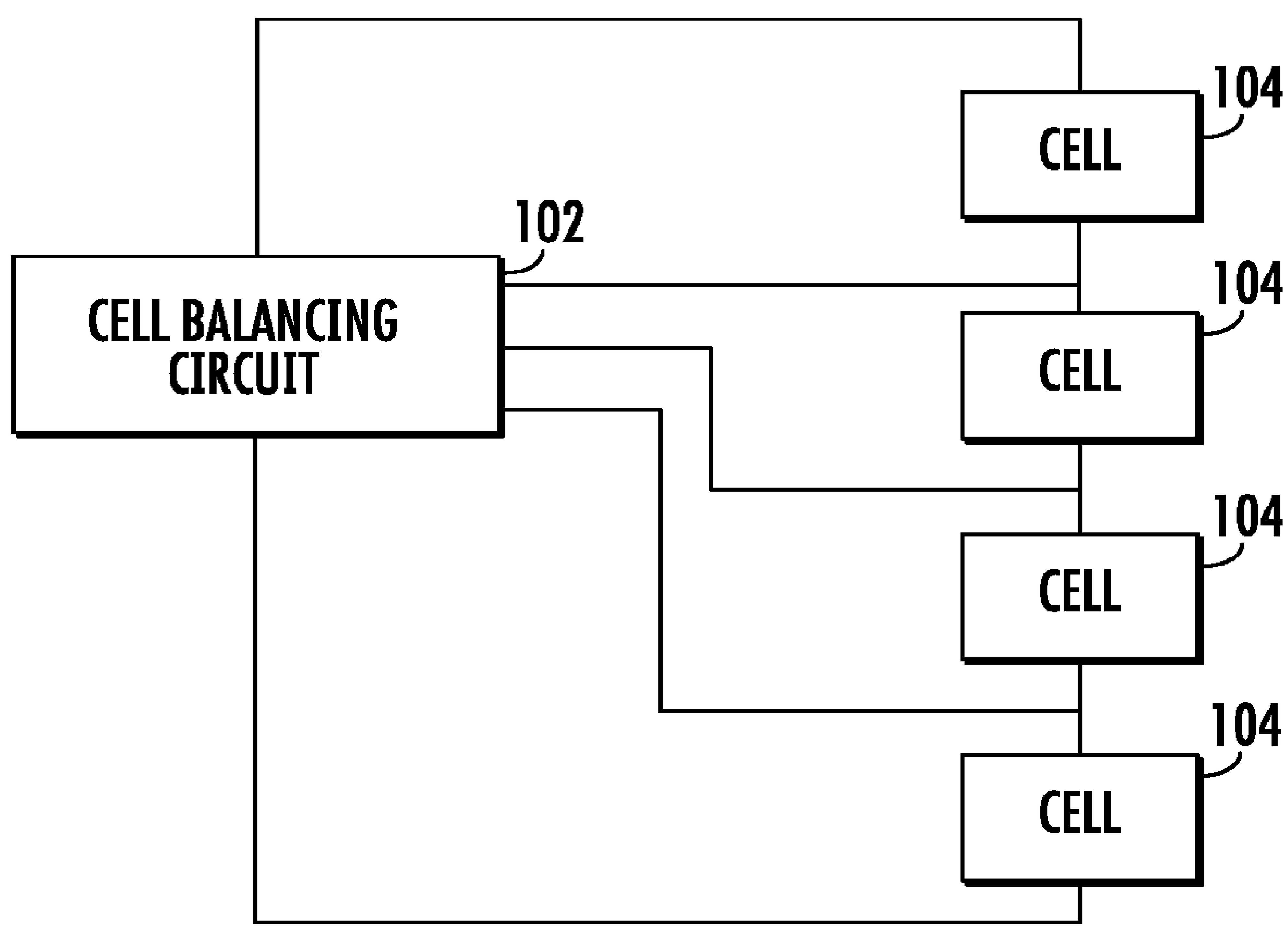
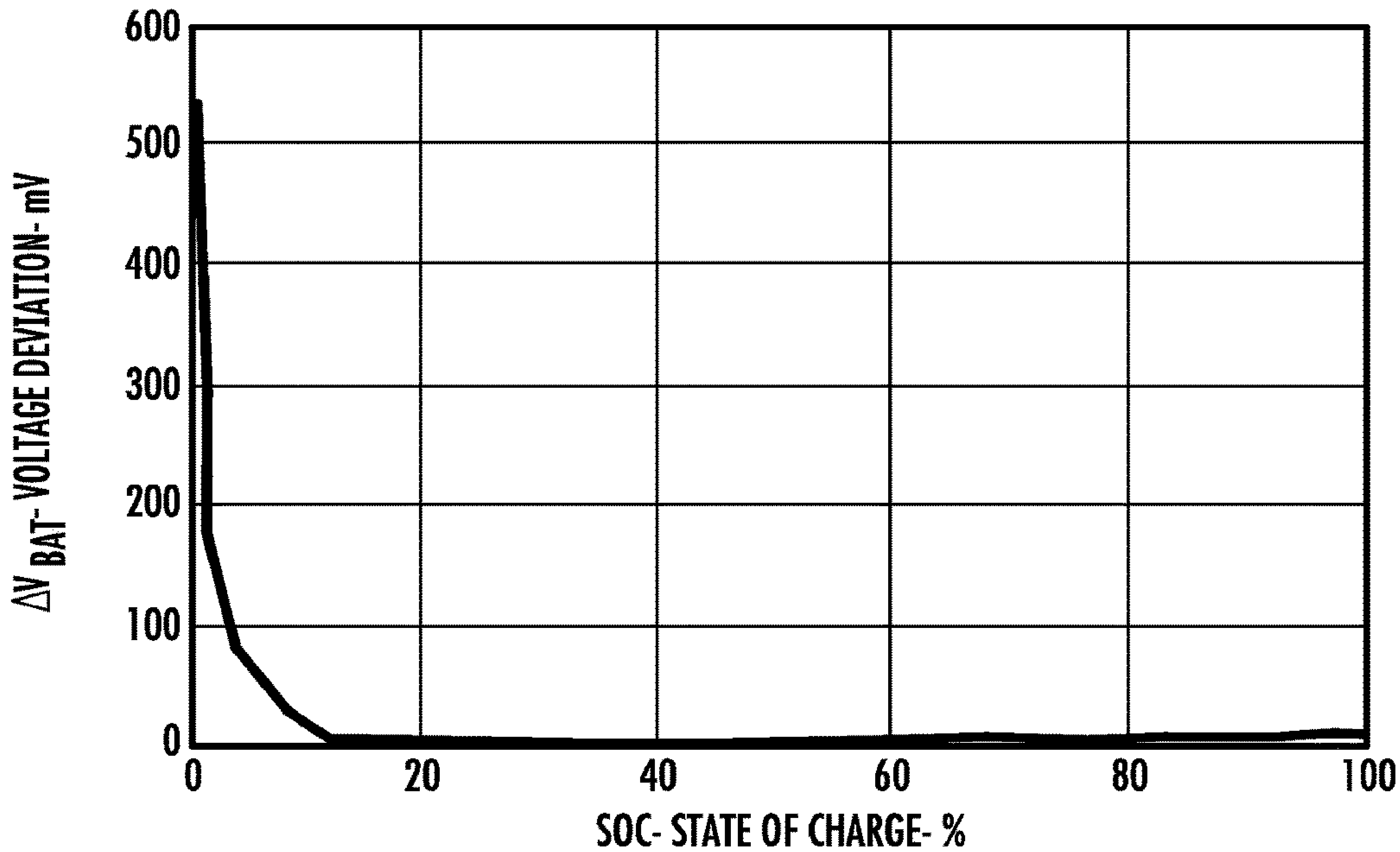
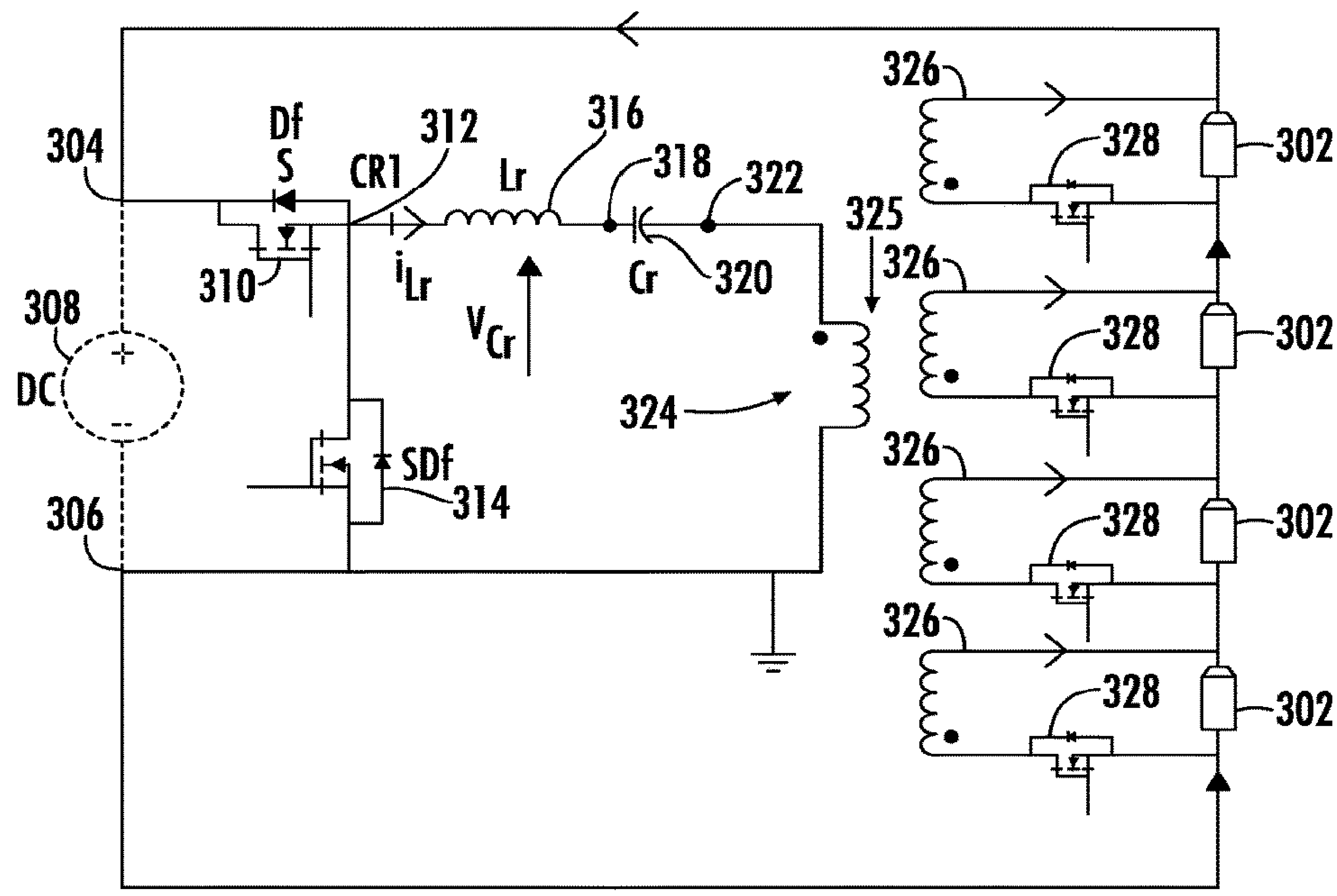

CELL BALANCING CIRCUIT
102
CELL
104
CELL
104
CELL
104
CELL
104

FIG. 1



600
500
400
300
200
100
0
ΔV_{BAT}- VOLTAGE DEVIATION- mV
0
20
40
60
80
100
SOC- STATE OF CHARGE- %

FIG. 2



304
Df
S
CR1
312
Lr
316
318
322
325
326
328
302
310
i_{Lr}
V_{Cr}
Cr
320
308
DC
324
SDf
314
306

FIG. 3

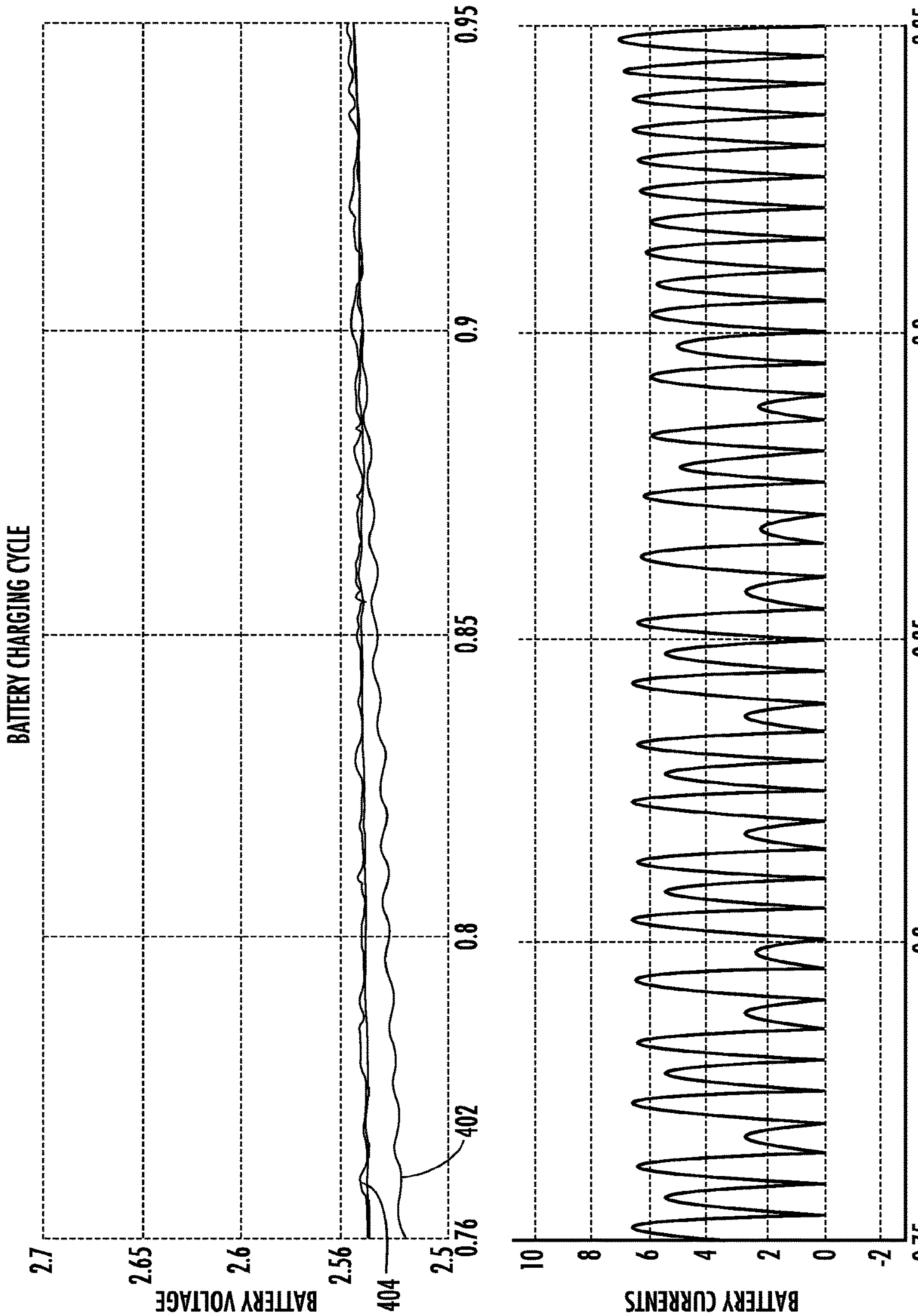

BATTERY CHARGING CYCLE
BATTERY VOLTAGE
2.7
2.65
2.6
2.56
2.5
0.76
0.8
0.85
0.9
0.95
402
404
BATTERY CURRENTS
10
8
6
4
2
0
-2
0.75
0.8
0.85
0.9
0.95
TIME

FIG. 4

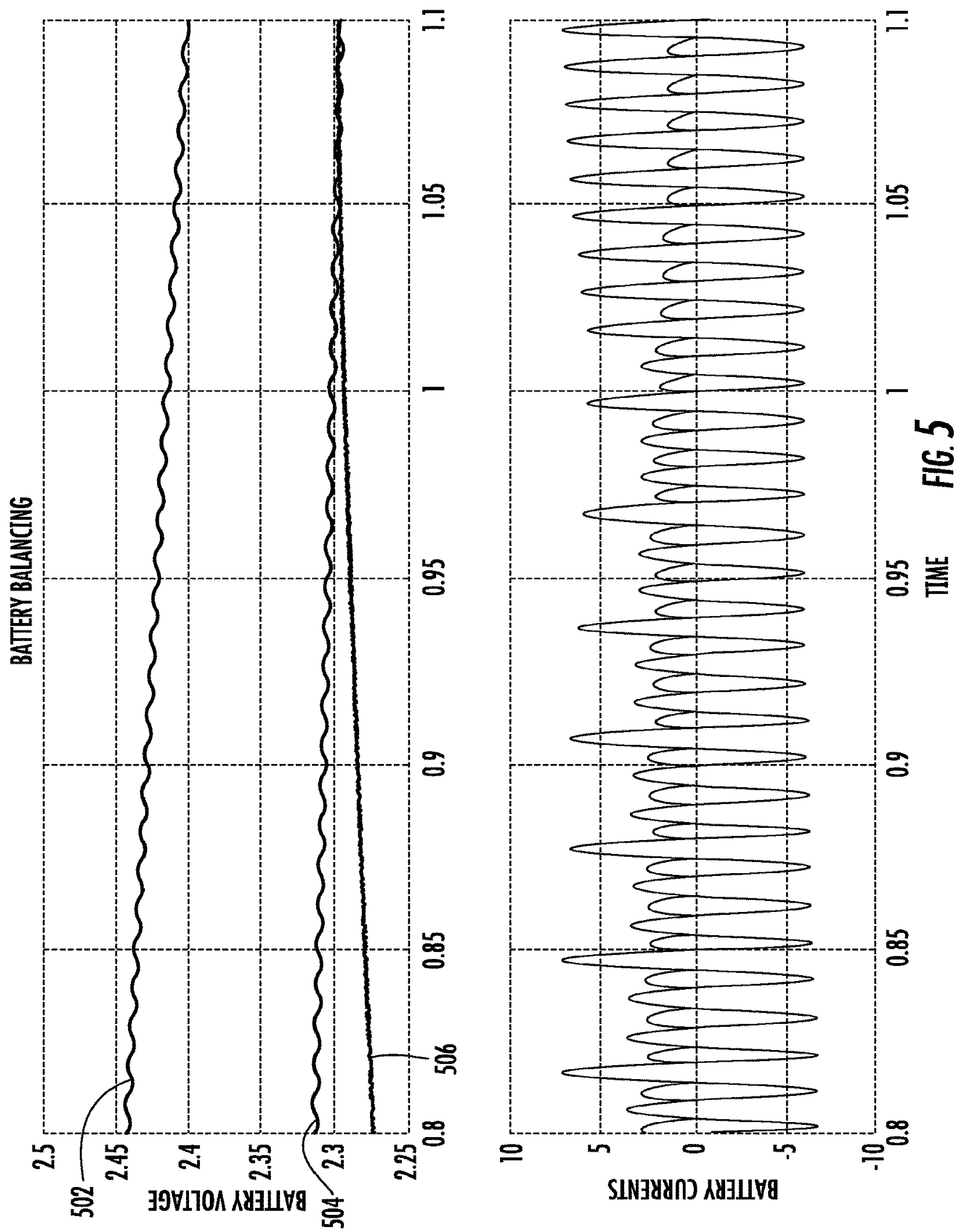

BATTERY BALANCING
BATTERY VOLTAGE
2.5
2.45
2.4
2.35
2.3
2.25
502
504
506
0.8
0.85
0.9
0.95
1
1.05
1.1
BATTERY CURRENTS
10
5
0
-5
-10
TIME

FIG. 5

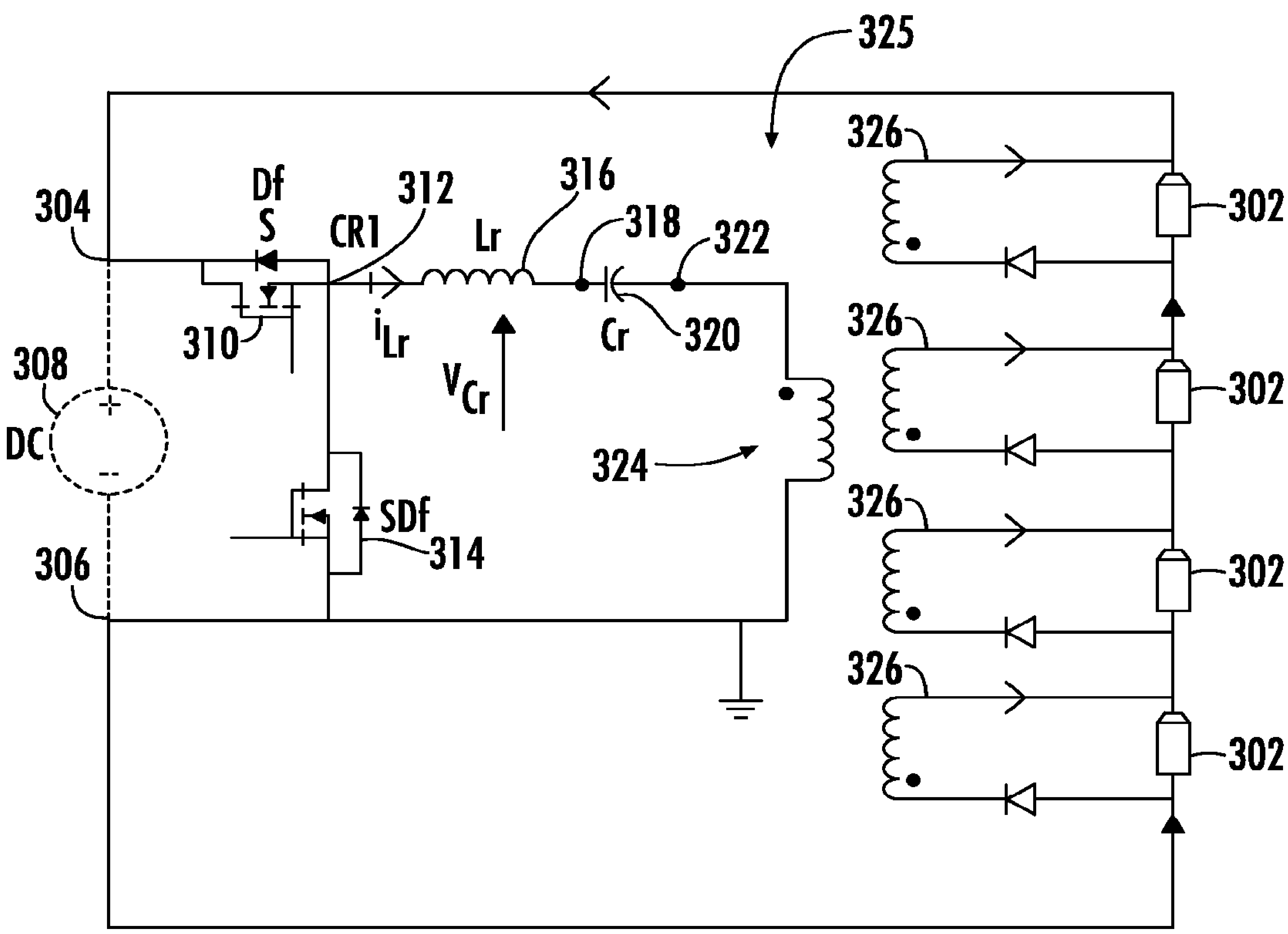

325
326
302
326
302
326
302
326
302
304
Df
S
CR1
312
Lr
316
318
322
310
iLr
Cr
320
308
VCr
DC
324
SDf
314
306

FIG. 6

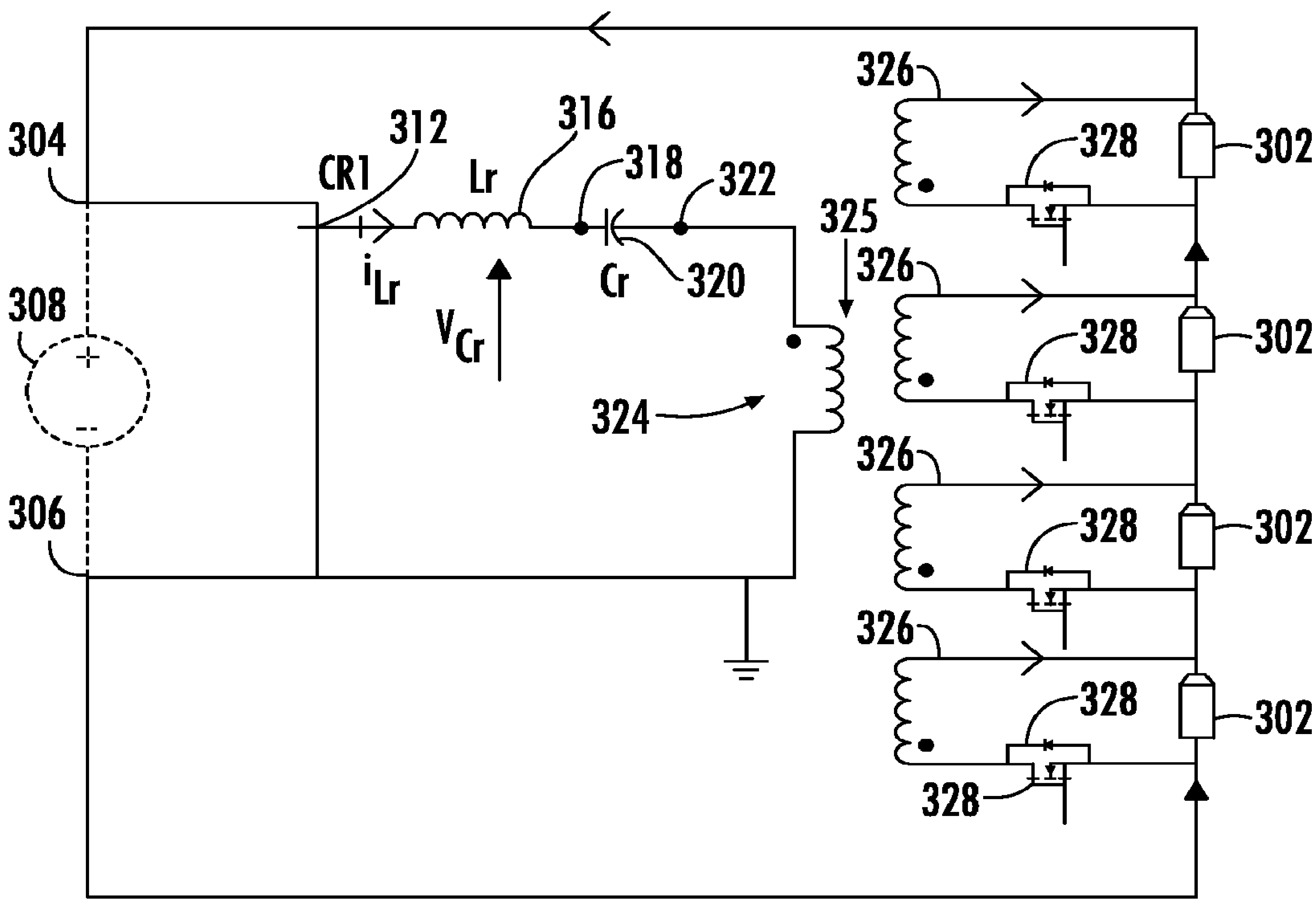
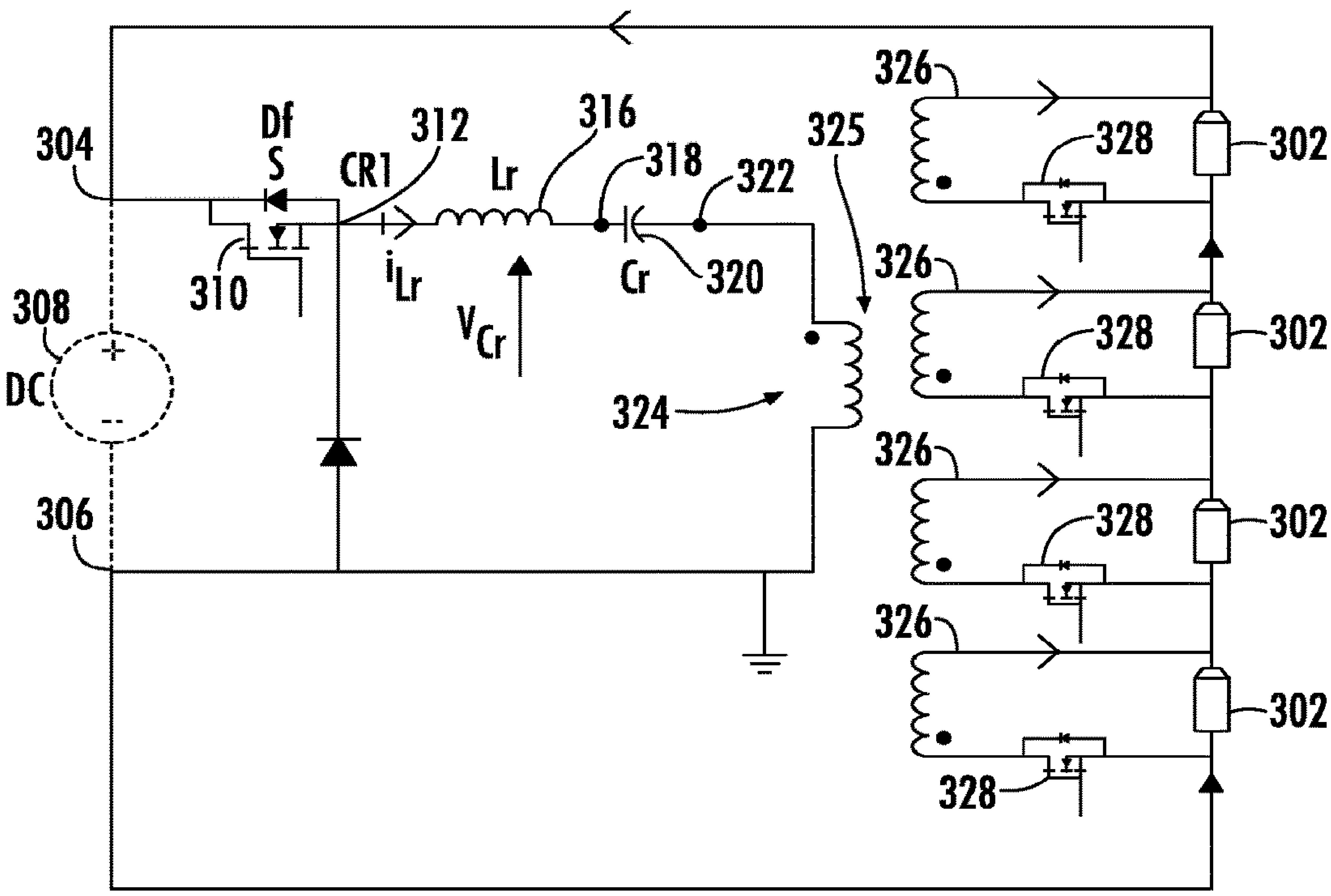

304
308
306
312
CR1
316
Lr
318
322
i_{Lr}
V_{Cr}
Cr
320
325
324
326
328
302

FIG. 7



304
Df
S
312
CR1
316
Lr
318
322
325
326
328
302
308
DC
310
iLr
VCr
Cr
320
324
306

FIG. 8

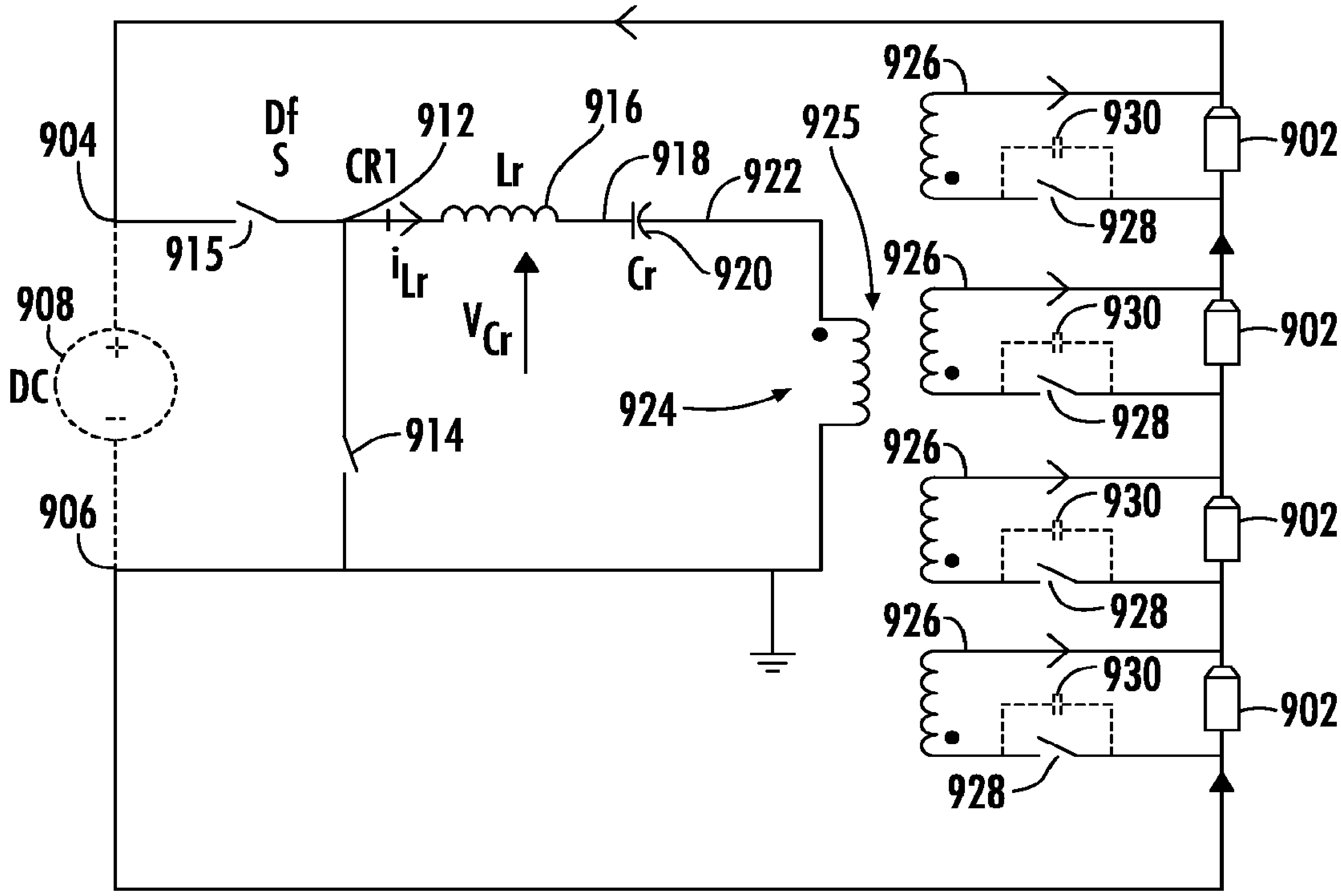

904
Df
S
CR1
912
916
Lr
918
922
925
926
930
902
928
915
i_{Lr}
Cr
920
908
DC
V_{Cr}
924
914
906

FIG. 9

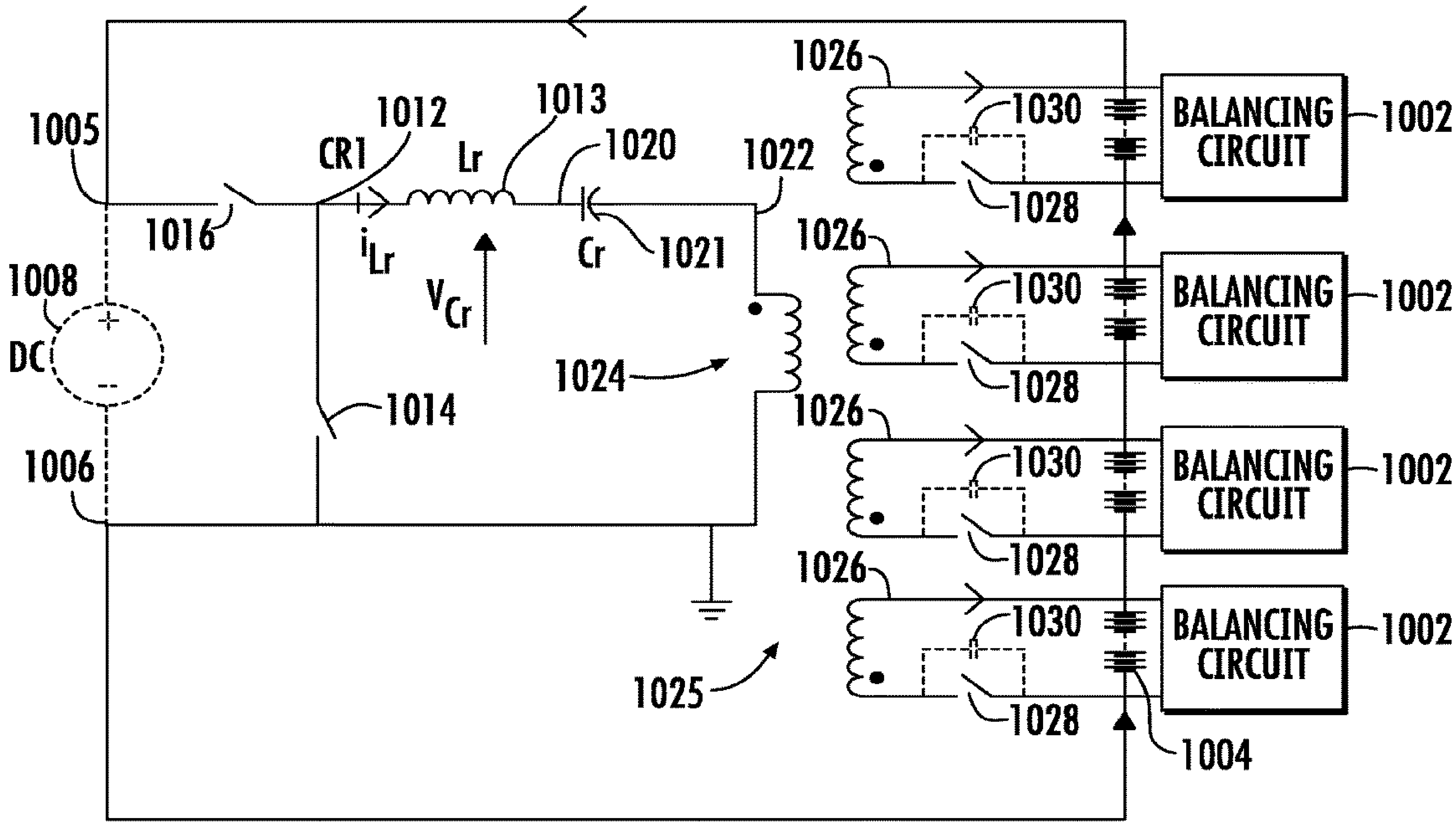
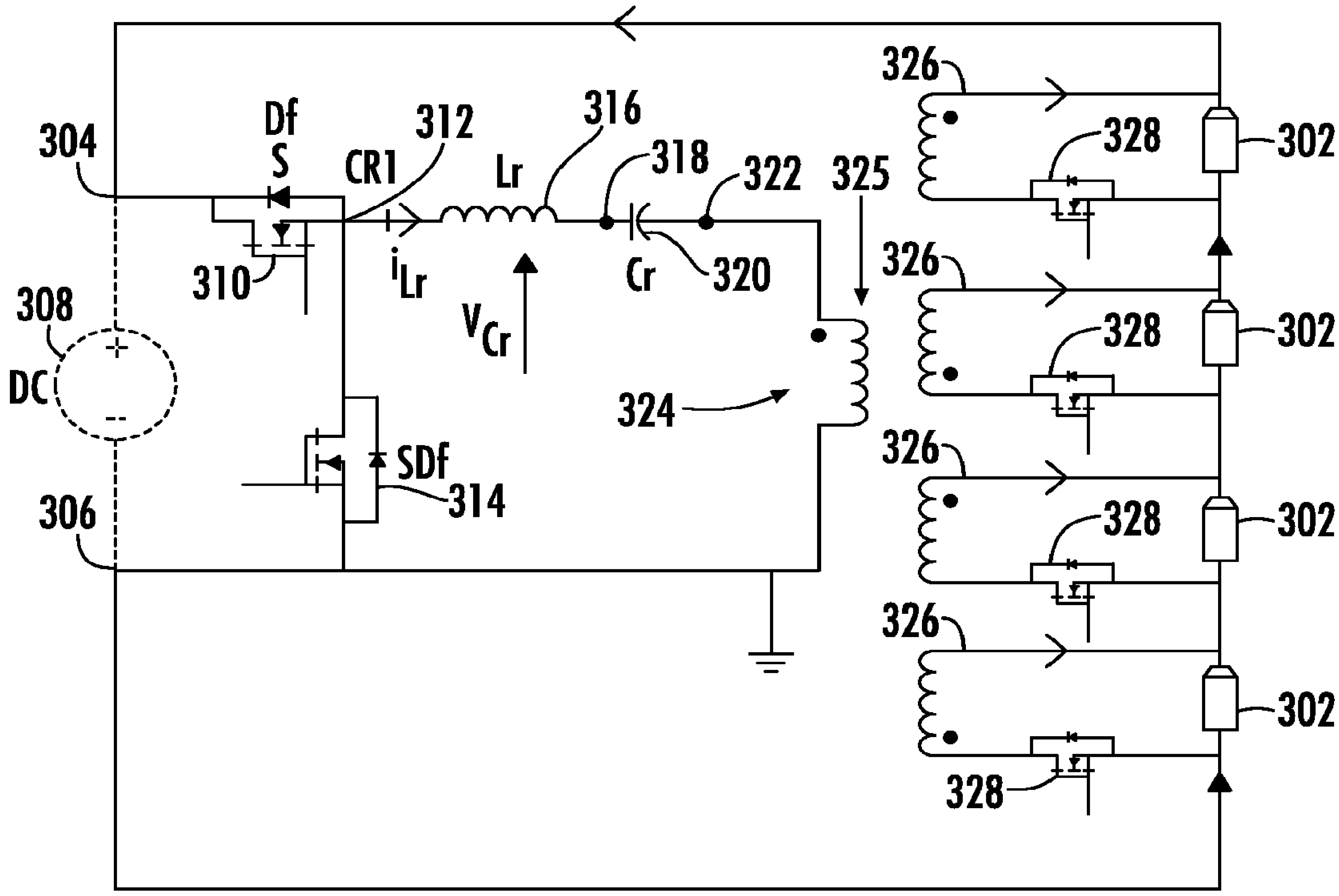

1005
1016
1012
CR1
1013
Lr
1020
1022
i_{Lr}
V_{Cr}
Cr
1021
1008
DC
1024
1014
1006
1025
1026
1030
1028
BALANCING CIRCUIT
1002
1004

FIG. 10



304
Df
S
CR1
312
316
Lr
318
322
325
326
328
302
308
DC
+
--
310
i_{Lr}
V_{Cr}
Cr
320
324
SDf
314
306

FIG. 11

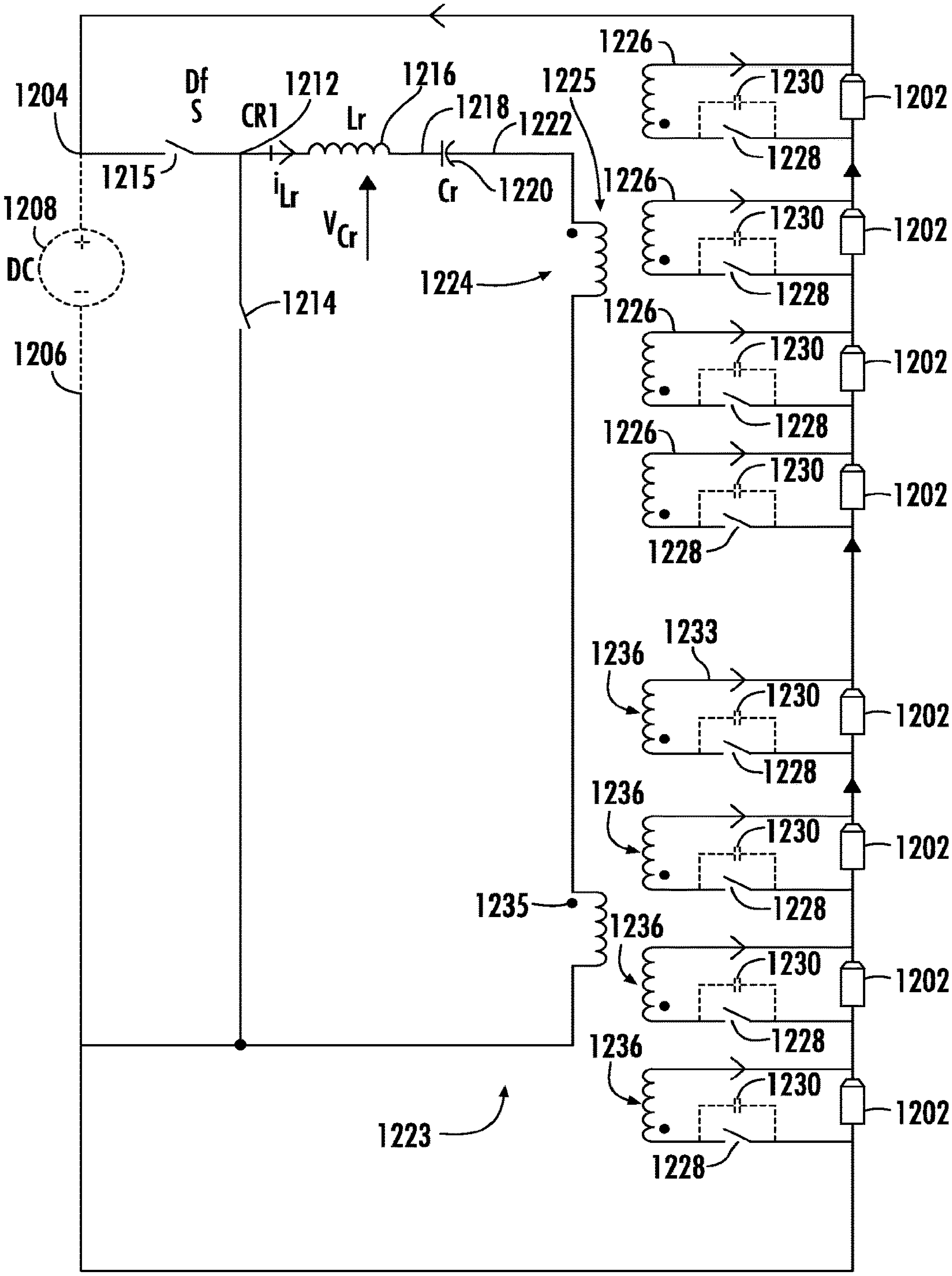

1204
Df
S
CR1
1212
1216
Lr
1218
1222
1225
1215
i_{Lr}
V_{Cr}
Cr
1220
1208
DC
1224
1214
1206
1226
1230
1202
1228
1236
1233
1235
1223

FIG. 12

SYSTEM AND METHOD FOR CELL BALANCING AND CHARGING USING A SERIALLY COUPLED INDUCTOR AND CAPACITOR

PRIORITY CLAIM

The present application is a Continuation of copending U.S. patent application Ser. No. 12/650,775, filed Dec. 31, 2009, now U.S. Pat. No. 9,397,508; which application claims priority to U.S. Provisional Patent Application Ser. No. 61/180,618, filed May 22, 2009, and U.S. Provisional Patent Application Ser. No. 61/244,643, filed Sep. 22, 2009; all of the foregoing applications are incorporated herein by reference in their entireties.

RELATED APPLICATION DATA

This application is related to U.S. patent application Ser. No. 14/750,702 entitled SYSTEM AND METHOD FOR CELL BALANCING AND CHARGING USING A SERIALLY COUPLED INDUCTOR AND CAPACITOR filed on Jun. 25, 2015, and which is incorporated herein by reference in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding, reference is now made to the following description taken in conjunction with the accompanying Drawings in which:

FIG. **1** is a block diagram illustrating the connection of a cell balancing circuit with a series connection of battery cells;

FIG. **2** illustrates voltage differences between two cells as a function of the percent of state of charge of the cells;

FIG. **3** illustrates a schematic diagram of a circuit for charging and balancing of cells;

FIG. **4** illustrates the battery charging cycle during transition;

FIG. **5** illustrates the battery discharging cycle during transition;

FIG. **6** illustrates an alternative embodiment of FIG. **3**;

FIG. **7** illustrates yet another embodiment of the circuit of FIG. **3**;

FIG. **8** illustrates yet a further alternative embodiment of the circuit of FIG. **3**;

FIG. **9** illustrates a further embodiment of the battery charging and balancing circuit;

FIG. **10** illustrates a nested configuration of the charging and balancing circuit;

FIG. **11** is a block diagram of an alternative embodiment of the circuit of FIG. **3** wherein the polarities are reversed on some of the secondary winding portions; and

FIG. **12** illustrates an alternative embodiment including the plurality of series connected transformer portions enabling a stacked configuration that is scalable.

DETAILED DESCRIPTION

Referring now to the drawings, wherein like reference numbers are used herein to designate like elements throughout, the various views and embodiments of a system and method for cell balancing and charging are illustrated and described, and other possible embodiments are described. The figures are not necessarily drawn to scale, and in some instances the drawings have been exaggerated and/or simplified in places for illustrative purposes only. One of ordinary skill in the art will appreciate the many possible applications and variations based on the following examples of possible embodiments.

Cell balancing and charging systems provide the ability to charge a series connection of battery cells using a single source. Systems using multiple lithium ion or super capacitor cells require balancing of the individual cells in order to maximize the energy available from the batteries and to prolong the life of the system. Resistive balancing systems for charging cells dissipate excess charge as heat are one common solution but these types of systems waste energy. Energy transfer systems which are based on a "nearest neighbor" inductive or capacitive energy transfer reduce the amount of wasted energy but are complex and generally provide less than satisfactory results when transferring charge over a distance of several cells. Thus, there is a need for a cell balancing and charging system that solves the dual problems of balancing the state of charge of cells within a stack of battery cells without dissipating the energy in an associated resistor and further providing efficient transfer of charge to any cell in the stack without a distance penalty. The common way of balancing cells within a multi cell battery is by discharging the highest cell through a pass element or alternatively by passing the charge from a pass element to an adjacent cell.

Referring now to the drawings, and more particularly to FIG. **1**, there is illustrated a configuration of a cell balancing circuit **102** which is connected with a series connection of battery cells **104**. The charge level on a particular battery cell **104** may be moved from one cell to another in order to balance the charge load across each of the cells **104**. The cell balancing circuit **102** is responsible for carrying out this cell balancing/charging functionality. Various types of systems, as discussed herein above, exist for transferring the charge from one cell within a cell stack to an adjacent cell. However, these systems are overly complex and expensive and suffer from poor efficiency when transferring charge over several cells such as from one end of the cell stack to the other.

Referring now to FIG. **2**, there is illustrated the voltage differences between two cells as a function of the percent state of charge. When batteries of different impedances or voltages are connected in series, the state of charge of the entire pack is limited. At a low state of charge percentage the voltage deviation is very high and can approach 500 millivolts deviation. The voltage deviation significantly decreases and approaches zero as the state of charge approaches 20%. Thus, during the charging cycle, the battery including a higher charge voltage may end up overcharged and damaged, or alternatively, a battery including a lower charge level may end up undercharged in order to protect the higher charge battery. In either case, the battery's cells will not reach their maximum charge voltage. During discharge, the lower charge battery may pull the total capacity of the series connection to a low level and prevent the taking of maximum charge from the system.

Referring now to FIG. **3**, there is illustrated a first embodiment of a circuit for providing charging and load balancing of a series connection of battery cells **302**. The series connection of battery cells **302** are connected between node **304** and node **306**. A charging voltage is supplied to the battery cells **302** via a voltage source **308** provided between nodes **304** and **306**. Node **306** comprises the ground node while node **304** comprises the input voltage node. A high-side switching transistor **310** MOSFET has its source/drain path connected between node **304** and node **312**. A low-side switching transistor **314** MOSFET has its drain/source path connected between node **312** and the ground node **306**.

A resonant tank circuit consisting of inductor **316** and capacitor **320** is connected between node **312** and node **322**. The inductor **316** is connected between node **312** and node **318**. The capacitor **320** is connected in series with the inductor **316** between node **318** and node **322**. A primary side **324** of a transformer **325** is connected to node **322** and to the ground node **306**. The secondary side of the transformer **325** includes a number of secondary portions **326**, each of which are connected across the terminals of an associated battery cell **302**. The polarity of adjacent secondary side portions **326** of the transformer are reversed from each other. A switching MOSFET **328** has its drain/source path connected between the secondary portion **326** of the transformer **325** and the negative terminal of the associated battery cell **302**. The switch **328** would receive control signals from a control circuit (not shown) which also controls switching transistors **310** and **314**.

During the charging cycle, the system of FIG. **3** is based upon a resonant converter for every switching cycle, and the amount of energy that is put into the resonant tank by the voltage source **308** is then transferred to the secondary side portions **326**. The lowest charged voltage cells will then take most of the energy transmitted to the secondary side **326** from the resonant tank and the highest charged voltage cells the least. Thus, the charge is transferred to the second portion **326** in proportion to the charge on the associated battery cells. In order to add more protection and control, the switch **328** is added in series with each secondary portion **326** to increase or decrease the overall impedance of the battery cell **302**. This allows selective charging of the battery cells such as might be required when a cell is to be charged to a higher voltage than other cells. Thus, the cells are balanced during charging.

As can be seen in FIG. **4**, the lowest voltage cells are taking all of the energy provided by the resonant tank while the higher voltage battery cells are sitting idle until the lower battery cells catch up in charge value with the higher value tanks. Thus, waveform **402** represents the charging battery voltage of the lower charge battery cell while waveform **404** represents the higher voltage battery.

During the discharge cycle, the input to the primary side **324** of the transformer **325** will comprise the total series voltages of all of the battery cells **302**. The energy is circulating from all of the battery cells **302** back to the lowest charged cells. FIG. **5** illustrates the ampere hour taking every cycle from every cell is the same while the energy put back into the system is higher for the lower voltage batteries. Thus, waveform **502** represents the highest voltage battery cell, waveform **504** represents the next highest voltage battery cell while waveform **506** represents the lowest voltage battery cell.

The main difference between previous solutions and the implementation described herein above with respect to FIG. **3**, is that the energy is taken from the entire stack of battery cells **302** and then redistributed back based on the battery cell that needs more energy than the other battery cells. This scheme permits very simple systems which automatically distribute charge without the need for a sophisticated control mechanism. A more sophisticated implementation is possible in which balancing may be performed using complex algorithms in a manner that maintains optimal performance with a variety of systems over the entire system life. The system may be equally implemented as a charger, balancer or both.

Referring now to FIG. **6**, there is illustrated an alternative implementation of the circuit of FIG. **3** wherein the MOSFET switches **328** between the transformer secondaries **326** and the battery cells **302** are replaced by diodes **602**. In another implementation illustrated in FIG. **7**, the switches feeding the tank may be removed and the tank input grounded. In this system the switches between the transformer secondaries and the cells are replaced by a suitable arrangement of switches and conducting elements. Energy is passed to and from the tank circuit by selective use of the secondary side switches. E.g. the secondary side in FIG. **2** becomes both primary and secondary depending on the configuration of the switch elements. Alternatively, as illustrated in FIG. **8**, the lower drive MOSFET **314** may be replaced by a diode **802**. In an alternative control scheme, the currents through the transformer primary **324** may be sensed to determine a current limit providing an on time termination point for the circuit and a switch termination timing to determine when to turn off the switching transistors **310** and **314**.

Referring now to FIG. **9**, there is illustrated a further embodiment of the charging/balancing circuit of FIG. **3**. The series connection of battery cells **902** are connected between node **904** and node **906**. A charging voltage is supplied to the battery cells **902** via a voltage source **908** provided between nodes **904** and **906**. Node **906** comprises the ground node while node **904** comprises the input voltage node. A high-side switch **910** is connected between node **904** and node **912**. A low-side switch **914** is connected between node **912** and the ground node **906**. A resonant tank circuit consisting of inductor **916** and capacitor **920** is connected between node **912** and node **922**. The inductor **916** is connected between node **912** and node **918**. The capacitor **920** is connected in series with the inductor **916** between node **918** and node **922**.

A primary side **924** of a transformer **925** is connected to node **922** and to the ground node **906**. The secondary side of the transformer **925** includes a number of secondary portions **926**, each of which are connected across the terminals of the associated battery cell **902**. A switch **928** is connected between the secondary portion **926** of the secondary side **926** of the transformer **925** and the negative terminal of the associated battery cell **902**. The switch **928** would receive control signals from a control circuit (not shown) which also controls switches **915** and **914**. In addition to the switch **928** connected between the transformer secondary portion **926** and the battery cell **902**, a capacitor **930** is connected in parallel with the switch **928**. In this scheme, current may be directed to individual cells **902** through the selective use of the secondary side switches **928** allowing programmable charge balancing or charge redirection to deliberately produce an unbalanced condition.

Referring now also to FIG. **10**, there is illustrated a nested balancing system. Nested arrangements are possible in which each of the battery cells are replaced by the balancing circuit **1002** as described previously with respect to FIG. **3** and a series of battery cells **1004**. The circuit of FIG. **10** comprises a series connection of battery cells **1004** are connected between node **1005** and node **1006**. A charging voltage is supplied to the battery cells **1004** via a voltage source **1008** provided between nodes **1005** and **1006**. Node **1006** comprises the ground node while node **1005** comprises the input voltage node. A high-side switch **1016** is connected between node **1005** and node **1012**. A low-side switch **1014** is connected between node **1012** and the ground node **1006**.

A resonant tank circuit consisting of inductor **1013** and capacitor **1021** is connected between node **1012** and node

1022. The inductor 1013 is connected between node 1012 and node 1018. The capacitor 1021 is connected in series with the inductor 1013 between node 1020 and node 1022. A primary side 1024 of a transformer 1025 is connected to node 1022 and to the ground node 1006. The secondary side of the transformer 1025 includes a number of secondary portions 1026, each of which are connected across the terminals of the associated battery cell stack 1004. A switch 1028 is connected between the secondary portion 1026 of the secondary side 1026 of the transformer 1025 and the negative terminal of the associated battery cell stack 1004. The switch 1028 would receive control signals from a circuit which also controls switches 1016 and 1014.

As mentioned previously, rather than a single cell, a series of cells 1004 are connected across each of the secondary portions 1026 of the secondary side of the transformer. Connected across these cells 1004 is the balancing circuit described previously with respect to FIG. 3. Thus, the battery cells 1004 would comprise the source 308 and the balancing circuit 1002 would connect with the source at nodes 304 and 306. Thus, each stack of cells 1004 includes its own balancing system 1002 such that nested balancing systems may be produced which optimizes the complexity/performance trade off.

In an alternative embodiment of the circuit of FIG. 10, the switches 1016 and 1014 feeding the resonant tank may be removed and the tank input grounded. In this implementation, the switches 1028 between the transformer secondaries 1026 and the cell stacks 1004 are replaced by a suitable arrangement of switches and conducting elements. Energy is passed to and from the resonant tank circuit by the selective use of the secondary side switches 1028. Thus, the secondary side becomes both the primary and secondary depending on the configuration of the switching elements.

In yet a further embodiment illustrated in FIG. 11, the circuitry is configured in substantially the same manner as that described with respect to FIG. 3. However, the polarities on the secondary side portions 326 are altered such that some (ideally half) of the secondary windings have one polarity and the remainder of the secondary windings have the opposite polarity. The actual sequence between the reversed polarities within the secondary windings is not important. The benefit that this configuration provides is that charge may be transferred on both half cycles of the transformer. The first half cycle feeds the secondaries with one polarity and the second half cycle feeds those with the opposite polarity.

Referring now to FIG. 12, there is illustrated a further embodiment that comprises a stacked configuration including additional transformer 1233 placed in series with the first transformer 1225. The series connection of battery cells 1202 are connected between node 1204 and node 1206. A charging voltage is supplied to the battery cells 1202 via a voltage source 1208 provided between nodes 1204 and 1206. Node 1206 comprises the ground node while node 1204 comprises the input voltage node. A high-side switch 1210 is connected between node 1204 and node 1212. A low-side switch 1214 is connected between node 1212 and the ground node 1206. A resonant tank circuit consisting of inductor 1216 and capacitor 1220 is connected between node 1212 and node 1222. The inductor 1216 is connected between node 1212 and node 1218. The capacitor 1220 is connected in series with the inductor 1216 between node 1218 and node 1222.

A primary side 1224 of a first transformer 1225 is connected to node 1222 and to the ground node 1206. The secondary side of the transformer 1225 includes a number of secondary portions 1226, each of which are connected across the terminals of the associated battery cell 1202. A switch 1228 is connected between the secondary portion of the secondary side 1226 of the transformer 1225 and the negative terminal of the associated battery cell 1202. The switch 1228 would receive control signals from a control circuit (not shown) which also controls switches 1215 and 1214. In addition to the switch 1228 connected between the transformer secondary portion 1226 and the battery cell 1202, a capacitor 1230 is connected in parallel with the switch 1228. In this scheme, current may be directed to individual cells 1202 through the selective use of the secondary side switches 1228 allowing programmable charge balancing or charge redirection to deliberately produce an unbalanced condition.

In the second transformer 1223 of the stacked configuration, a primary side 1235 of the transformer 1223 is connected in series with the primary side 1224 of the first transformer 1225. Additionally, a further series of transformer secondaries 1236 are connected across additional battery cells 1202 in series with the transformer secondary portion 1226 of transformer 1225. As in the first portion of the circuit, a switch 1228 would receive control signals from a control circuit (not shown). In addition to the switch 1228 connected between the transformer secondary portion 1236 and the battery cell 1232, a capacitor 1230 is connected in parallel with the switch 1228. The stacked configuration is completely scalable. As many sections as needed may be added in series. Thus, rather than the two illustrated in FIG. 12, any number may be further added. A single pair of switches 1215 and 1214 and a single tank circuit consisting of inductor 1216 and capacitor 1220 then feed the series connected transformer windings.

Thus, the main difference between previous solutions and the present disclosure is that the energy is taken from the entire cell stack and redistributed based upon the cells that need more energy than the other. The scheme permits very simple systems which automatically charge without the need of a sophisticated control mechanism. More sophisticated implementations are possible in which the balancing may be performed using complex algorithms in a manner that maintains the optimal performance with a variety of systems and over the entire system life.

It will be appreciated by those skilled in the art having the benefit of this disclosure that this system and method for cell balancing and charging provides an improved manner of charging/balancing a stack of battery cells. It should be understood that the drawings and detailed description herein are to be regarded in an illustrative rather than a restrictive manner, and are not intended to be limiting to the particular forms and examples disclosed. On the contrary, included are any further modifications, changes, rearrangements, substitutions, alternatives, design choices, and embodiments apparent to those of ordinary skill in the art, without departing from the spirit and scope hereof, as defined by the following claims. Thus, it is intended that the following claims be interpreted to embrace all such further modifications, changes, rearrangements, substitutions, alternatives, design choices, and embodiments.

What is claimed is:

1. A method, comprising:

generating an input current through serially coupled primary windings of multiple transformers, wherein generating the input current includes generating the input current in response to a resonating of an inductor and a capacitor coupled in series with the primary windings; and generating, in response to the input current, charge-balancing currents each flowing through a respective secondary winding of each of the transformers and a respective one of a set of serially connected battery cells such that each charge-balancing current has a magnitude that is related to a voltage on the respective at least one of the set of battery cells.

2. The method of claim 1 wherein generating the input current includes generating the input current in response to a voltage across at least one of the battery cells.

3. The method of claim 1 wherein generating the input current includes generating the input current in response to a current generated by at least one of the battery cells.

4. The method of claim 1 wherein generating the input current includes generating the input current in response to a current generated by a power supply.

5. The method of claim 1 wherein generating the charge-balancing currents includes generating at least one of the charge-balancing currents flowing in only one direction.

6. The method of claim 1 wherein generating the charge-balancing currents includes generating at least one of the charge-balancing currents only while the input current is flowing in a direction.

7. An apparatus, comprising:

an input circuit configured to generate an input current, wherein the input circuit includes an inductor and a capacitor in series with a first primary winding and is configured to generate the input current by causing the inductor and capacitor to resonate; and

transformers including

primary windings including the first primary winding coupled together in series and configured to receive the input current, wherein each of the transformers includes a respective one of the primary windings, and

secondary windings each configured to generate, in response to the input current, a respective charge-balancing current flowing through a respective at least one of battery cells that are coupled together in series such that the respective charge-balancing current has a magnitude that is related to a voltage across the respective at least one of the battery cells, wherein the each transformer further includes one or more of the secondary windings.

8. The apparatus of claim 7 wherein the input circuit is configured to generate the input current in response to a voltage across at least one of the battery cells.

9. The apparatus of claim 7 wherein the input circuit is configured to generate the input current in response to a current generated by at least one of the battery cells.

10. The apparatus of claim 7 wherein the input circuit is configured to generate the input current in response to a current generated by a power supply.

11. The apparatus of claim 7 wherein each of at least one of the secondary windings is configured to generate a respective charge-balancing current flowing in only one direction.

12. The apparatus of claim 7 wherein each of at least one of the secondary windings is configured to generate a respective charge-balancing current only while the input current is flowing in a direction.

13. A system, comprising:

a ground node;

battery cells coupled in series to the ground node;

an input circuit configured to generate an input current, wherein the input circuit includes an inductor and a capacitor in series with a first primary winding and is configured to generate the input current by allowing the inductor and capacitor to resonate; and

transformers including

primary windings including the first primary winding coupled together in series and configured to receive the input current, wherein each of the transformers includes a respective one of the primary windings, and

secondary windings each configured to generate, in response to the input current, a respective charge-balancing current flowing through a respective at least one of the battery cells such that the respective charge-balancing current has a magnitude that is related to a voltage across the respective at least one of the battery cells, wherein the each transformer further includes one or more of the secondary windings.

14. The system of claim 13, further comprising:

a power supply coupled to the ground node and configured to generate a power-supply current; and

wherein the input circuit is configured to generate the input current in response to the power-supply current.

15. An apparatus, comprising:

transformers each including:

a respective primary winding coupled in series with the primary windings of the other transformers, and

at least one respective secondary winding each having first and second nodes configured to be coupled across at least one of a set of series-coupled battery cells;

a circuit configured to generate an input current through the primary windings;

electronic devices each having a first node coupled to one of the first and second nodes of a respective one of the secondary windings and having a second node configured to be coupled to a respective one of the battery cells; and

a series-resonant circuit in series with the primary windings.

16. The apparatus of claim 15, further comprising a ground node coupled to the series combination of the primary windings.

17. The apparatus of claim 15 wherein the series-resonant circuit includes an inductor in series with a capacitor.

18. The apparatus of claim 15, further comprising:

a ground node, and;

wherein the series-resonant circuit is coupled between the ground node and a series combination of the primary windings.

19. The apparatus of claim 15, further comprising:

an input node;

a ground node;

wherein the series-coupled battery cells are coupled between the input node and the ground node; and

wherein the circuit includes

a first switch coupled between the input node and the primary windings; and

a second switch coupled between the ground node and the primary windings.

20. The apparatus of claim 15 wherein each electronic device includes a respective switch.

21. The apparatus of claim 15, further comprising capacitors each coupled across a respective one of the electronic devices.

22. The apparatus of claim 15 wherein each of the secondary windings is configured to have a same winding direction.

23. The apparatus of claim 15 wherein the secondary windings of each transformer each have approximately a same number turns as the other secondary windings of the transformer.

24. A system, comprising:
a ground node;
battery cells coupled in series to the ground node;
transformers each including:
a respective primary winding in series with the primary windings of the other transformers, and
at least one respective secondary winding each coupled to a respective one of the battery cells;
a circuit configured to generate an input current through the primary windings and including a series-resonant circuit serially coupled between the primary windings and the ground node; and
electronic devices each coupled between a respective one of the secondary windings and a respective one of the battery cells.

25. A system, comprising:
a ground node;
battery cells coupled in series to the ground node;
transformers each including:
a respective primary winding in series with the primary windings of the other transformers, and
at least one respective secondary winding each coupled to a respective one of the battery cells;
a circuit configured to generate an input current through the primary windings;
electronic devices each coupled between a respective one of the secondary windings and a respective one of the battery cells; and
wherein the circuit includes:
an input node;
a series-resonant circuit having a first node coupled to the primary windings and having a second node;
a first transistor coupled between the input node and the second node of the series-resonant circuit; and
a second transistor coupled between the ground node and the second node of the series-resonant circuit; and
wherein the battery cells are coupled in series between the input node and the ground node.

26. The system of claim 25 wherein each of the secondary windings is configured to have a same winding direction.

27. A system, comprising:
a ground node;
battery cells coupled in series to the ground node;
transformers each including:
a respective primary winding in series with the primary windings of the other transformers, and
at least one respective secondary winding each coupled to a respective one of the battery cells;
a circuit configured to generate an input current through the primary windings;
electronic devices each coupled between a respective one of the secondary windings and a respective one of the battery cells;
wherein the circuit includes:
an input node;
a series-resonant circuit having a first node coupled to the primary windings and having a second node;
a first transistor coupled between the input node and the second node of the series-resonant circuit; and
a second transistor coupled between the ground node and the second node of the series-resonant circuit; and
a power supply coupled between the ground node and the input node.

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